The 22nd Annual David S. Snipes/Clemson Hydrogeology Symposium Field Trip Guidebook

A Geologic Transect from the Piedmont to the Blue Ridge along US Hwy 76 in South Carolina

Table Rock gneiss exposed at Ramsey Creek Falls, Chau Ram Park, SC

Field Trip Leaders: Sergey Goretoy and Scott Brame

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Scott E. Brame and Sergey Goretoy
Environmental Engineering and Earth Sciences
Clemson University
Clemson, SC 29634

Introduction

This geologic transect is based on a field trip (Hatcher, 2001a) which was part of the ninth Annual Clemson Hydrogeology Symposium. The primary focus of this trip is to view the major geologic transitions that occur heading west from the Walhalla nappe across the Eastatoee fault and Brevard Zone along US Hwy 76 in South Carolina. Since the original field trip in 2001, Garihan and Clendenin (2007) have identified the Eastatoee fault as a major structural transition between the migmatitic rocks of the Walhalla nappe and the non-migmatitic Henderson Gneiss. Observations by the authors of this guide have confirmed the descriptions of rock types identified previously by Hatcher (2000, 2001b), Hatcher and Liu (2001), and Hatcher, Acker, and Liu, (2001), but insights provided by Clendenin and Garihan (2007) during their mapping have been applied to reinterpret some of the original structural relationships.

Geologic Interpretation

Recent geologic mapping in the northwestern part of South Carolina (Garihan, 2005; (Garihan and others, 2005) divides the western Inner Piedmont thrust stack into (southeast to northwest) the Six Mile, Walhalla, and Jocassee thrust sheets with the Brevard Zone acting as the western boundary. Individual formations that are present on each thrust sheet are listed in Figure 1. The ductile Eastatoee fault (Garihan and Clendenin, 2007) and the Seneca fault (Garihan, 2001) lie, respectively, at the base of the Walhalla nappe and the base of the structurally higher Six Mile thrust sheet. The Eastatoee fault is marked by progressive ductile deformation with resulting grain size reduction, shearing, and flattening fabrics in the footwall as the fault is approached. Similar relationships pertain to the Seneca fault at the base of the Six Mile thrust sheet. Those characteristics reveal that the Eastatoee fault is a major ductile structure, and it is of regional extent.

The Eastatoee fault redefines the spatial distribution and lithostratigraphic character of the Walhalla nappe. Its identification re-assigns the greenschist grade Chauga River Formation rocks of the 'Chauga belt' above the fault to the Walhalla nappe. The Jocassee thrust sheet is composed of Henderson Gneiss.

The tectonic stacking used to interpret the structures on this field trip is detailed in Figure 1. The structural relationships (Clendenin and Garihan, 2007) and the order of units in the Walhalla nappe (Garihan and others, 2005) have been established in the northwest part of South Carolina. This field trip extends these relationships to rocks along Hwy 76 west of Westminster.

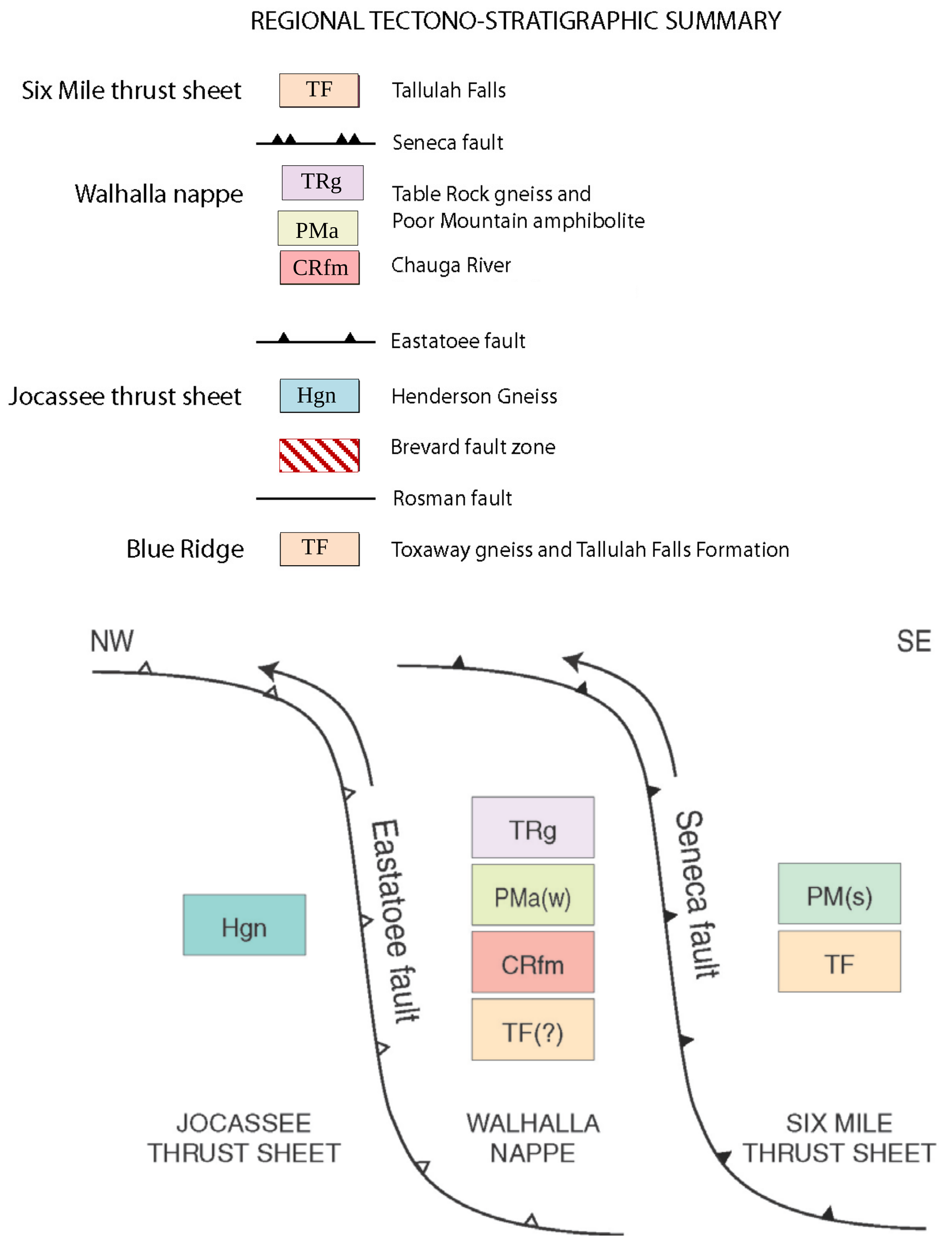

Figure 1. Tectonic stacking applied to the interpretation of formations on this field trip (Clendenin and Garihan, 2013; Goforth, Garihan, and Brame, 2012). TF=Tallulah Falls Formation, CRfm=Chauga River Formation, PMa(w)= Poor Mountain Formation amphibolite, TRg=Table Rock gneiss, Hgn=Henderson Gneiss

Descriptions of Rock Formations

Note: The following rock descriptions are taken from Goforth and others (2012), but the descriptions are from the geologic map explanations listed in the reference section.

Walhalla Thrust Sheet

Poor Mountain Formation amphibolite. (Middle Ordovician)

Resistant amphibolite and minor interlayered metasiltstone, schist, and garnet-muscovite-quartz phyllonite occur in a belt of variable width. Contacts with Table Rock gneiss are sharp, whether intrusive and modified by folding or faulted.

Amphibolite is mafic, fine-crystalline, and thinly layered with leucocratic, fine- to coarse-crystalline pods and layers of quartz and feldspar parallel to foliation. Thin interlayers (a few centimeters thick) in amphibolite are composed of green, fine-crystalline, granoblastic feldspar, epidote, and quartz. Polyphase folding is observed in mesoscopic exposures. The unit includes minor muscovite-biotite “button” schist. (The bent, tapered ends of lenses of mica in the schist produced by ductile deformation resemble “buttons” when weathered out of the rock onto the surface.) The Poor Mountain Formation amphibolite map unit also includes garnet-muscovite-quartz phyllonite, quartz-muscovite metasandstone, clinoamphibole schist, and garnet-hornblende gneiss. Chemical weathering of amphibolite forms a distinctive, limonite-rich rock, or it produces float with limonite rinds on fresher amphibolite cores.

Chauga River Formation metasiltstone and garnet schist. (Cambrian-Early Ordovician)

Metasiltstone and schist constitute a thin, continuous belt of resistant rocks. Ductile deformation features, folds, and boudinage are common in these cliff-forming rocks. Foliation in Chauga River Formation rocks is dominantly a secondary, transposition foliation.

Two end-member lithologies make up a range of compositional variation in this metapelitic map unit. Metasiltstone is dark gray, fine-crystalline, poorly layered, well foliated, locally schistose garnet-muscovite-biotite-porphyroclastic feldspar-quartz gneiss. With increased mica this lithology becomes a dark brown, fine- to medium-crystalline, garnet-muscovite-biotite “button” schist. Almandine garnet (1-5 mm) is idioblastic. Coarse muscovite flakes or aggregates of finer muscovite in the schist form conspicuous “fish” (lozenge-shaped bundles), in a groundmass of black, aligned, fine-crystalline biotite. Schistose rocks locally contain resistant layers and pods of medium- to coarse-crystalline granitoid material and pegmatite, locally foliated (sheared). The schist displays S-C fabric. Also present are finely laminated muscovite-quartz metasiltstone, biotite-quartz metasiltstone, mica metaquartzite, and minor amphibolite.

Table Rock gneiss. (Middle Ordovician)

The main lithology of the Table Rock gneiss is a biotite quartzo-feldspathic gneiss, which locally is leucocratic. The gneiss is gray to tan, fine- to medium-crystalline, and moderately well layered compositionally. Foliation is defined by aligned micas or discontinuous, lenticular aggregates of quartz and feldspar. Sheared varieties of quartzo-feldspathic gneiss contain quartz ribbons a few millimeters thick defining foliation or muscovite, due to K-feldspar breakdown during ductile deformation. A well-developed mineral lineation occurs on foliation surfaces in many places.

The Table Rock gneiss map unit also includes muscovite-biotite-quartz-feldspar gneiss,

micaceous biotite gneiss, biotite-feldspar augen gneiss, hornblende-quartz-feldspar gneiss, poorly layered, poorly foliated, biotite granitoid gneiss, and aplite, pegmatite with local biotite selvedges, and quartz veins. Mafic rocks are layered amphibolite, biotite amphibolite, hornblende gneiss, and schist.

Jocassee Thrust Sheet

Henderson Gneiss. (Early-Middle Ordovician)

Henderson Gneiss is part of a large regional igneous body that commonly shows distinctive large feldspar crystals (< 5 cm) in a finer quartz, feldspar, and mica matrix. This biotite-microcline augen gneiss (granodiorite to granite in composition) is gray to dark gray and fine- to coarse-crystalline. The gneiss generally is well foliated. Compositional layering includes discontinuous mafic layers and lenticular aggregates of quartz and feldspar. Conspicuous pink, porphyroclastic microcline (0.5 to 5 cm) has white myrmekite rims. Owing to its coarser, feldspathic character, Henderson Gneiss is somewhat less resistant to weathering than the more quartzose Table Rock gneiss. Mylonitic fabric development is variable: protomylonite in sheared pegmatite, mylonite, and thinly layered ultramylonite in proximity to ductile faults and high strain zones. Highly sheared varieties of Henderson Gneiss contain either 1) quartz or microcline ribbons, or 2) recrystallized, fine-crystalline muscovite. On the outcrop scale, S-C fabric and strain partitioning (alternation of zones with differences in strained fabric) are present. Henderson Gneiss L-tectonites display excellent mica and quartz-feldspar mineral lineations on foliation planes.

In many outcrops the Henderson Gneiss is a light gray, locally leucocratic, layered biotite augen gneiss. Sheared textures indicate that homogeneous ductile deformation has produced a strongly layered rock from the originally heterogeneous granitoid. The presence of ultramylonitic Henderson Gneiss also indicates progressive ductile deformation. Biotite-augen gneiss is interlayered with resistant, light-gray, leucocratic, fine- to medium-crystalline, muscovite-quartz-feldspar gneiss; quartz-feldspar gneiss; fine- to medium-crystalline, biotite quarto-feldspathic gneiss; aplite, pegmatite, and quartz veins; and minor biotite amphibole gneiss.

Blue Ridge Rocks

Tallulah Falls Formation

The Tallulah Falls Formation consists of biotite granitoid gneiss with scattered, lenticular and irregular xenoliths of biotite quartzo-feldspathic gneiss. Occasional layers of equigranular calc-silicate rock (epidote, quartz, amphibole, garnet) occur within the contorted biotite quartzo-feldspathic gneiss xenoliths. There are also floating, disaggregated blocks of calc-silicate rock in the biotite granitoid gneiss. Calc-silicate rocks are common in the Tallulah Falls Formation regionally and form coherent quartzose float pieces at the surface when all other rock types have been deeply weathered and are difficult to identify.

Influence of the Brevard Fault Zone and Blue Ridge Escarpment

Clendenin and Garihan (2013) demonstrated that the Brevard Zone (BZ) reflects a complex history of multiple tectonic events. The west boundary of the BZ is the Rosman Fault, which represents the boundary between the Western Inner Piedmont and the Blue Ridge physiographic province. The east side of the BZ in the Salem and Reid quadrangles is defined by the South Boundary fault; here grain-size reduced Henderson Gneiss is thrust over Chauga River Formation phyllonites (Clendenin and Garihan, 2013). Multiple imbricate thrusting, called the 'Brevard Imbricate Stack' (BIS), is present between these two fault boundaries (Figure 2).

The BZ can be recognized as a linear topographic feature from Alabama to Virginia. In northeastern Georgia, northwestern South Carolina, and southwestern North Carolina, the fault zone is incised into the Dahlonega Plateau in northeastern Georgia and northwestern South Carolina. To the northeast, it traverses the 700-m Blue Ridge escarpment into North Carolina.

The present landscape appears to be a product of Cenozoic isostatic uplift in conjunction with the erosive power of streams preferentially flowing to the Atlantic Ocean rather than to the Mississippi drainage and the Gulf of Mexico. The result is that the escarpment and the Eastern Continental Divide are migrating westward through headward erosion and stream piracy (Prince, 2012).

This process has had a powerful influence on the landscape over time. The headward migrating streams will eventually intercept, or capture, streams that once flowed toward the southwest (and northeast such as the French Broad River in NC).

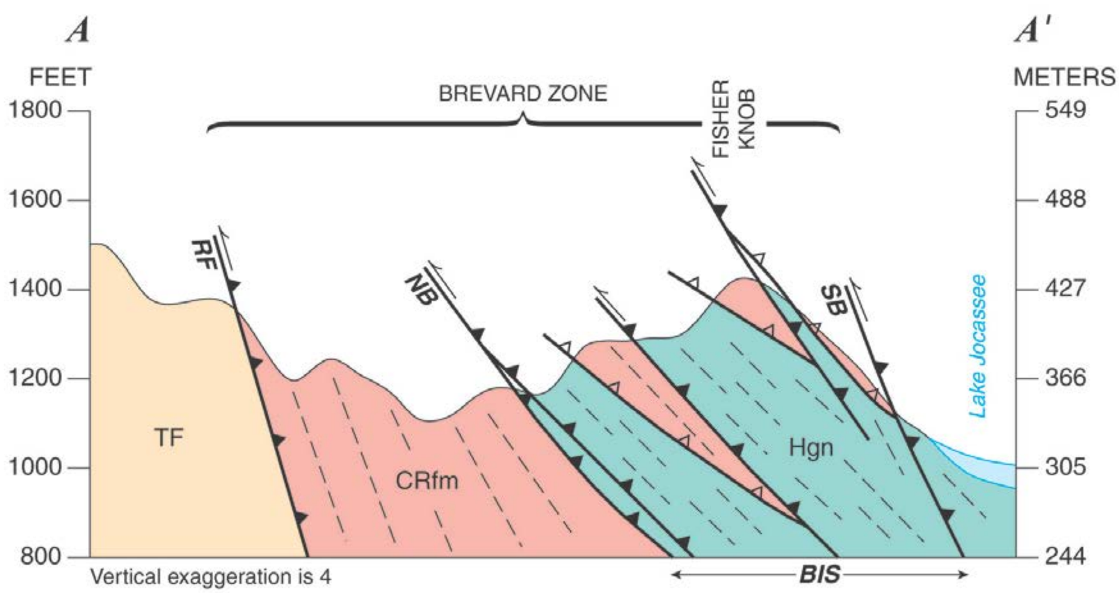

Figure 2. Structural relationships between alternating Henderson Gneiss and the Chauga River Formation rocks in the Brevard Zone. The fault surfaces that define the imbricate thrusting have been observed along the shores of Lake Jocassee (Clendenin and Garihan, 2013). Open sawtooth fault symbol marks the Eastatoee fault, which has been repeated by later Brevard Zone thrusting (solid sawtooth fault symbol). Note vertical exaggeration in the diagram, which makes the faults appear steeper than they actually are. Bounding the zone of thrust imbricates are: SB= South Boundary Fault, NF = North Boundary fault. RF = Rosman Fault.

Field Trip Stops (all Lat/Longs listed are in NAD83 or WGS84)

The locations of field trip stops are shown in Figure 3 along with their respective thrust sheets.

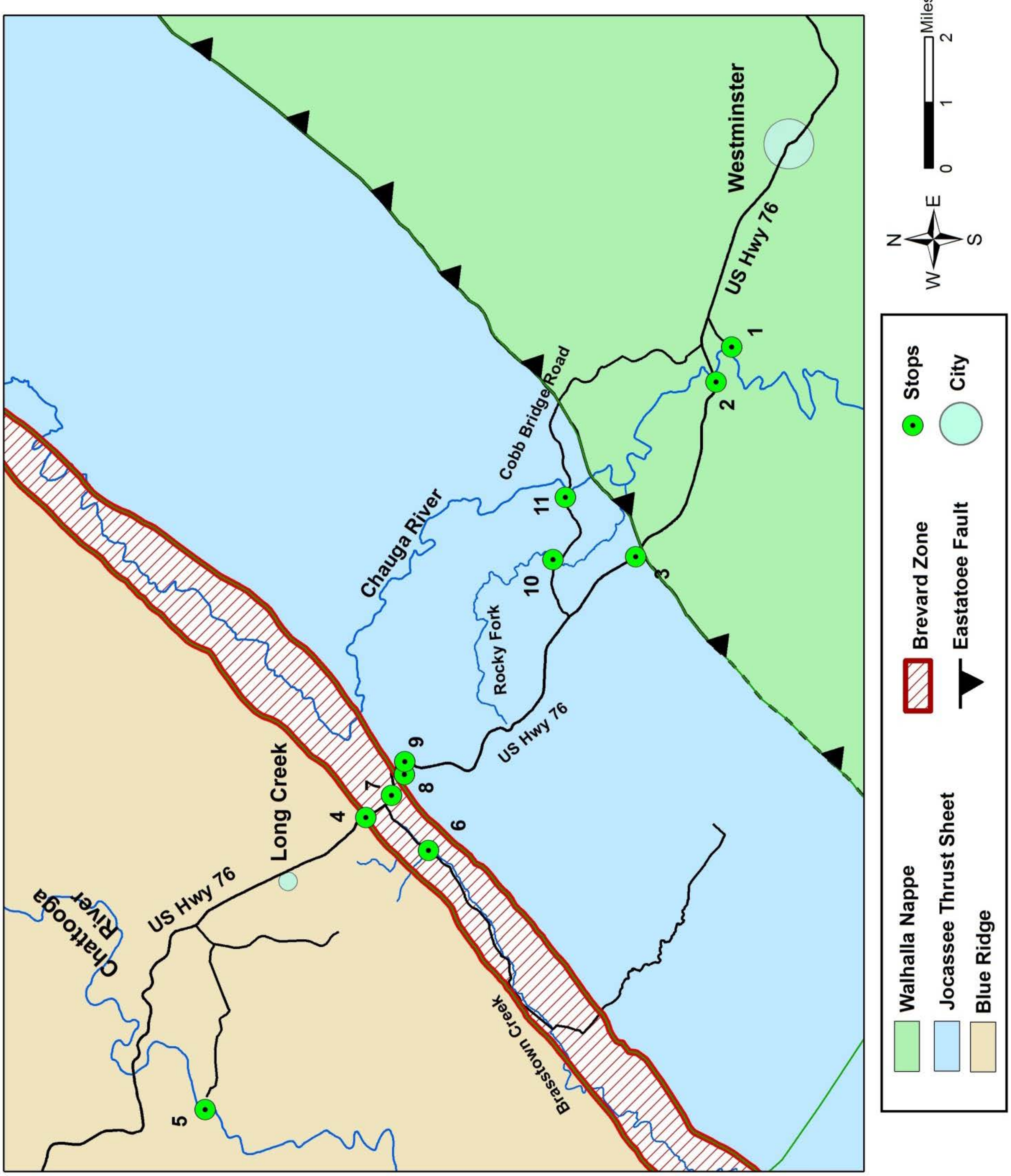

Figure 3: Field Trip stops along US Hwy 76 west of Westminster, SC.

Stop 1: Chau Ram County Park (34.682767, -83.14389)

Chau Ram Park is situated at the confluence of Ramsey Creek and the Chauga River. The falls on Ramsey Creek are the highlight of the park, but the rapids produced by the Chauga River are equally impressive. The falls are composed of biotite gneiss that belong to the Table Rock Formation.

Stop 2: Walhalla nappe rocks at Chauga River (34.685006, -83.153239)

This large weathered outcrop typifies many large exposures of Walhalla nappe rocks. The dark red color is indicative of weathered biotite and interbedded amphibolite stained by iron oxide (Figure 4). Both well-foliated and poorly foliated biotite quartzo-feldspathic gneisses are present. The exposure just to the west of this one along the road is typical limonite-weathered amphibolite. Amphibolite there resembles amphibolite of the Poor Mountain and the Tallulah Falls Formations.

Figure 4. Sergey reveals weathered gneiss and amphibolite at Stop 2. Note a steep, thinly banded 'tiger stripe' compositional layering in gneiss saprolite is visible in the dug out cuts. Steep foliations suggest west-vergent folds.

Stop 3: Henderson Gneiss (34.702802, -83.191944)

The pull off for this stop is in the parking lot of the Holly Springs Baptist Church. The tan, light colored soil in the road cut is a useful indicator in the region of the presence of Henderson Gneiss. Compared with the Table Rock gneiss, the Henderson Gneiss weathers to this light soil that is readily identifiable while driving. The road cut on the north side of the highway adjacent to the cemetery contains a fine-grained, weathered gneiss variety that lacks the characteristic feldspar (microcline) augen. Using the regional tectonic stacking model (Figure 1), the presence of Henderson Gneiss here indicates that the Eastatoee fault was crossed between Stop 2 and 3.

To view the characteristic augen, you will need to descend into the stream cut west of the old cemetery (north side of highway). Follow the highway west about 30-40 yards. The descent is steep and slippery with leaves. The lowermost layers exposed in the wall have prominent augen composed of feldspars that have been flattened (Figure 5). Some of the augen display pink colored microcline cores with white myrmekite rims that one sees typically in the Henderson Gneiss.

Figure 5. Prominent lenticular feldspar augen in mylonitic Henderson Gneiss near Holly Springs Baptist Church.

Stop 4: Rosman Fault (34.762654, -83.249652)

The large pull off on the right a few hundred yards west of the intersection of Hwy 76 and Brasstown Valley Road marks the position of the Rosman Fault (Figure 6). In the raised bank on the south side of the road, the Chauga River Formation schist is broken into irregular blocks that indicate brecciation characteristic of the Rosman fault zone. Scattered pieces of brecciated float are present. Highly altered rocks also can be found here, such as a mylonized rock colored purple and black with manganese and iron oxides. Further up the road (heading west), mylonitic Tallulah Falls gneisses are generally fine-crystalline. They mark rocks in the immediate footwall of the Brevard Zone

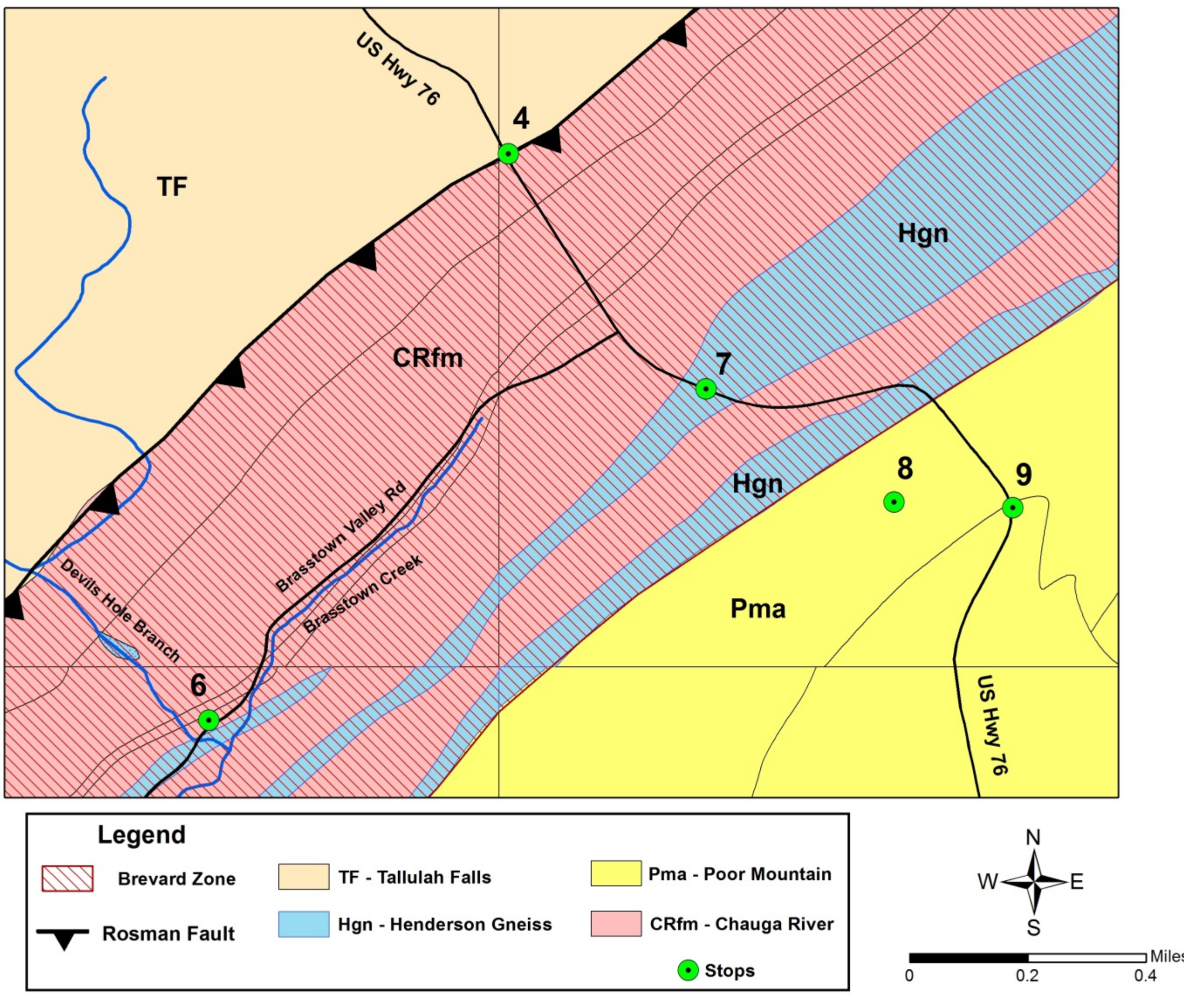

Figure 6. Location of Stop 4 and other stops in relation to Rosman Fault and Brevard Zone.

Stop 5: Woodall Shoals (34.798215, -83.314431)

Rocks of the Tallulah Falls Formation are spectacularly exposed at Woodall Shoals. The abrupt bend in the river (fracture controlled) has allowed large flood events to scour the river left bank down to a wide expanse of exposed bedrock. Woodall Shoals is popular with structural geology classes because it offers many large and small folds to visualize and measure. It exhibits structures (e.g., superposed folds) correlated with past deformational events that are assumed to have affected much of the Blue Ridge province. Bob Hatcher has described the exposure in detail.

The Woodall Shoals outcrop comprises alternating bands of northeast-southwest trending garnet-aluminous-schist, graywacke-schist and graywacke-schist-amphibolite of the Tallulah Falls Formation. Migmatitic biotite gneiss, amphibolite boudins, amphibolite layers, and pegmatites are found in lesser abundance along with a small (1 foot in diameter) ultramafic (soapstone) pod that has been suggested as a possible ophiolite (Figure 8).

Five generations of folds are present in the rocks. The earliest observable folds (F_2) are in the prominent amphibolite boudins (Figure 7). The foliation in the boudins is truncated by the dominant foliation in the biotite gneiss. Northeast trending folds (F_3) that are noncoaxial to the F_2 folds refold the boudins. The next deformational event that affected the Blue Ridge Rocks (F_4) and caused crenulation cleavage development is not observed here. However, F_5 and F_6 folds form a large dome and basin interference pattern at Woodall Shoals. This same phenomenon has been proposed for the formation of the very large Tallulah Falls Dome structure across the river in Georgia.

Figure 7. Amphibolite boudins at Woodall Shoals. During stretching, the more felsic biotite gneiss (gray), which has a lower melting temperature and a lower bulk viscosity, undergoes significant plastic deformation and flowage. It envelops and extends the more rigid (more viscous) amphibolite layers (black), creating distinct pods and blocky shapes. Evidence of boudin rotation (clockwise) is present on the right side, lower block.

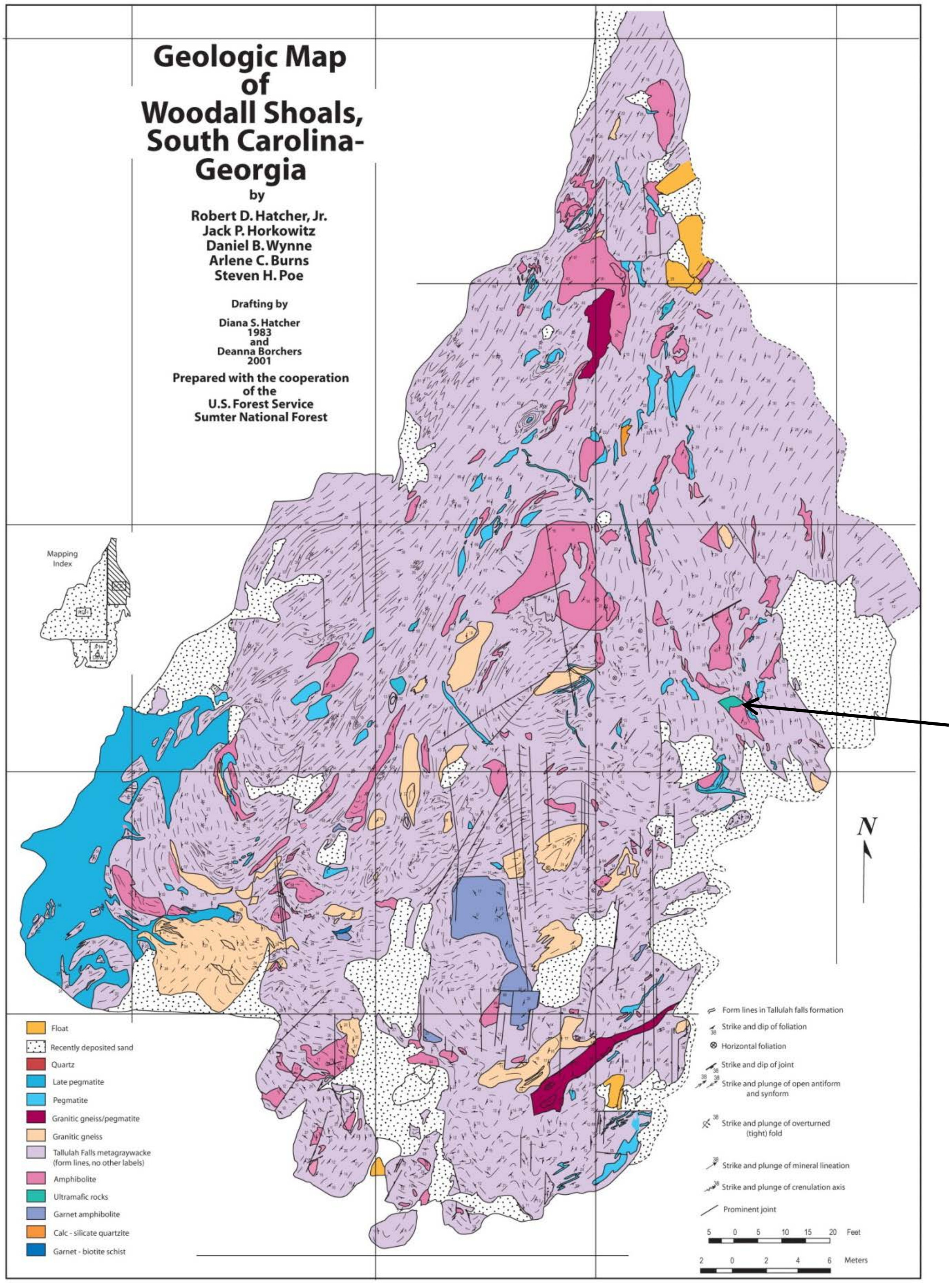

Figure 8. Woodall Shoals geologic map of Hatcher and others. The black arrow entering from the right points to the ultramafic rock.

Figure 9. Top drop at Woodall Shoals. This drop forms a dangerous keeper hole (recirculating hydraulic) that has been responsible for most of the known deaths on the Chattooga River. Those who died were typically poorly outfitted and inexperienced river runners, most of who were in inner tubes or some other inappropriate river craft. This hole is avoided by all but expert river runners at levels over 1.4 feet on the Hwy 76 gauge.

Stop 6: Brasstown Valley and Chauga River Stream Piracy (34.748788, -83.256976)

Note: This stop is on a state/county road, but the surrounding land is private. Please do not enter the private land without permission.

Brasstown Valley is situated in the Brevard Zone (Figure 6) and is underlain by the Chauga Fiver Formation. There are good exposures of button schist behind the gate on the west side of the road and in Devils Hole Branch that enters the valley from the west. This wide, well-developed valley is believed to represent the original streambed of the Chauga River prior to its capture by headward erosion of a westerly eroding stream (Acker and Hatcher, 1970) (Figure 10). The topographic position of these drainages suggests that stream capture has occurred. From its beginnings in the Mountain Rest, South Carolina area approximately 8 miles to the northeast, the Chauga parallels the Brevard Zone to within 1 mile north of Hwy 76. At that point, the river turns sharply to the southeast, where it has carved a deep and inaccessible gorge. It is hypothesized that a headward eroding stream cutting into the Blue Ridge Escarpment intercepted the Chauga watershed and captured the flow. Downstream of the sharp turn of the Chauga there are numerous “hanging valleys”. The term hanging valley refers to the waterfalls on the tributaries of the Chauga where they intersect the river. The formation of these waterfalls is consistent with the hypothesis that the

small headward eroding stream would experience much higher flows below the capture point than before the piracy, and thus would carve the main channel at a higher rate than the tributary streams, leaving them “hanging” above the main channel. Supporting evidence for this belief is the presence of the wide floodplain in Brasstown Valley. Brasstown Creek is a small stream that does not have a watershed area capable of creating such a significant valley feature.

At this location, Devils Hole Branch enters Brasstown Valley from the west and joins Brasstown Creek. Across the field is an old waterwheel used to grind corn in the past (Figure 11). A sluice was used to convey water from a small reservoir created by the damming of Devils Hole Branch. The dam is visible upstream of the mill, but the sluice is gone. Silas Butts owned this property before it was sold in the 1970s. His abandoned house is now boarded up.

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Figure 10: Topographic relationships between the Chattooga and Chattahoochee Rivers and the Chauga and Brasstown Creek suggest stream piracy has occurred.

Figure 11. Jack Garihan examining schist from the Chauga River Formation at Devils Hole Branch in Brasstown Valley with water-powered mill in the background.

Stop 7: Henderson Gneiss and Possible Imbricate Thrusting (34.756895, -83.244812)

The presence of two parallel Henderson Gneiss zones separated by Chauga River Formation rocks in the Brevard Zone (Figure 6, after Hatcher and others, 2001) raises the possibility of some combination of folding of the Eastatoee fault or/and imbricate thrusting, as seen along the shores of Lake Jocassee on the 2013 Clemson Hydrogeology Field Trip (Clendenin and Garihan, 2013). While the authors of this guide have not located evidence of imbricate thrusting and the exact location of the Henderson is still an ongoing endeavor, the possibility for imbricate thrusting exists. Refer back to Figure 2 to visualize the nature of the imbricate thrusting as observed at Lake Jocassee for a possible interpretation of the structural relationship between the Henderson Gneiss and Chauga River Formation at this location.

Stop 8: Chauga River Formation (34.75413, -83.24021): Optional Stop (if time allows)

This stop is in the parking lot of the Brasstown Baptist Church. The purpose of this stop is to observe an outcrop with schistose features that is markedly different from the schist observed in the Chauga River Formation. It belongs to the Poor Mountain Formation. The outcrop is located about 100 yards to the northwest of the church

Stop 9: Poor Mountain Formation (34.753989, -83.237298)

Highly weathered, thinly layered quartz-rich rocks are exposed in a roadside outcrop represent a fine grained meta-sandstone unit of the Poor Mountain Formation. A sudden color change found in exposed soils 100 yards to the west of this outcrop denote a transition from the Chauga River Formation in the west to the Poor Mountain Formation. From this point on, use color changes in the exposed soils to mark the transition from the darker Poor Mountain to the lighter soils typical of Henderson Gneiss.

Stop 10: Poor Mountain amphibolite on Rocky Fork (34.721127, -83.192558)

Note: this location is located on private land and permission to access this stop must be obtained from the landowner in advance. The owner lives on Corn Mill Road just up the hill.

Driving down Cobb Bridge Road from Hwy 76 (heading northeast/east), soil color changes from light gray/tan to dark red and back to light-colored again highlight the transition from Henderson Gneiss into Poor Mountain amphibolite and back into Henderson. At Rocky Fork, a large outcrop of Poor Mountain amphibolite is exposed in the stream and makes small shoals. The foliation of the amphibolite is N35°W, dipping 14.5^{o} NE.

At this location, there is also another water powered corn mill with an intact sluice that has been out of commission for many years (Figure 12).

Stop 11: Henderson Gneiss at Chauga River (34.718377, -83.178746)

The Henderson Gneiss is exposed in multiple places along Cobb Bridge Road and is identified by light, tan soils in contract to the darker red soils expressed by the weathering of amphibolite. Near Cobb Bridge, the Henderson Gneiss has abundant feldspar augen, and there the foliation is nearly flat lying.

Hatcher and Liu (2001, their cross section A-A') interpreted this geologic setting as a sheath fold with the Henderson sandwiched in between the Poor Mountain/Chauga River Formation on top with the Poor Mountain below. That is, the sheath fold (Figure 13) has an eroded elliptical-oval cross section that is cored by Poor Mountain amphibolite and quartzite, with a sheath of Henderson originally wrapping around it (like the sheath around a hunting knife blade). Hatcher and Liu did not specifically recognize the fault they show in their cross section A-A' as the Eastatoee Fault but they did identify a fault boundary that has been interpreted in this guide as the Eastatoee fault. Placing the Eastatoee Fault boundary to the east of the Henderson Gneiss is compatible with the tectonic stacking model of Garihan and Clendenin (2007). This structural relationship favors an interpretation where the ductile Eastatoee fault surface undulates and folds Walhalla nappe rocks into the Henderson. Thus, the contact between these different thrust sheets is defined by the Eastatoee fault surface. This tectonic stacking interpretation is reflected in Figure 14. Additional work is needed to support this hypothesis.

Figure 12. Water-powered corn mill with intact sluice along Rocky Fork. Shoals composed of Poor Mountain Formation amphibolite created the hydraulic gradient to power the water wheel.

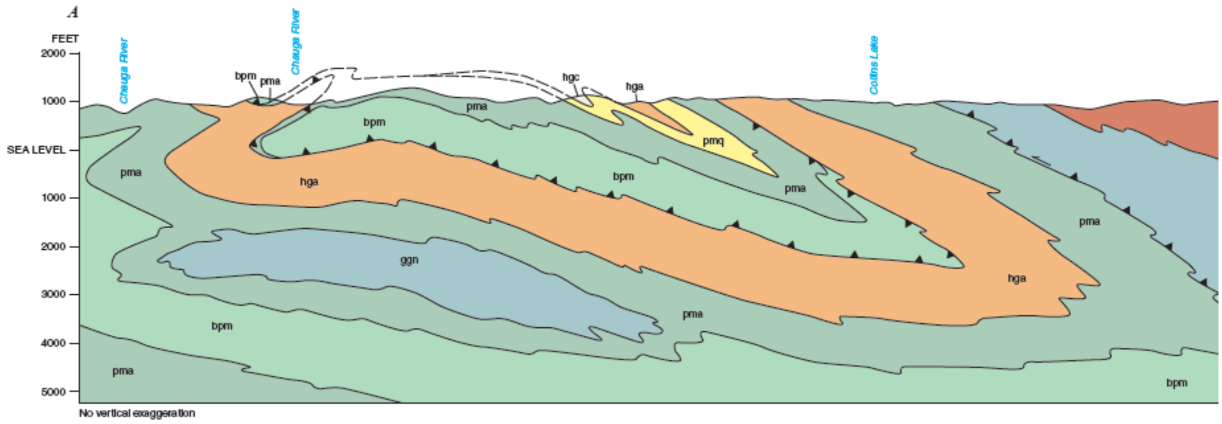

Figure 13. Portion of cross section A-A' of Hatcher and Liu (2001). Eastatoee fault lies between hga (Henderson) and Poor Mountain units (green shades and yellow). Cross section of a sheath fold, presumably formed during Acadian southwest-directed transport in the vicinity of the Brevard Zone (Merschat and others, 2005). This interpretive cross section position would lie across the extreme northeast edge of Figure 14.

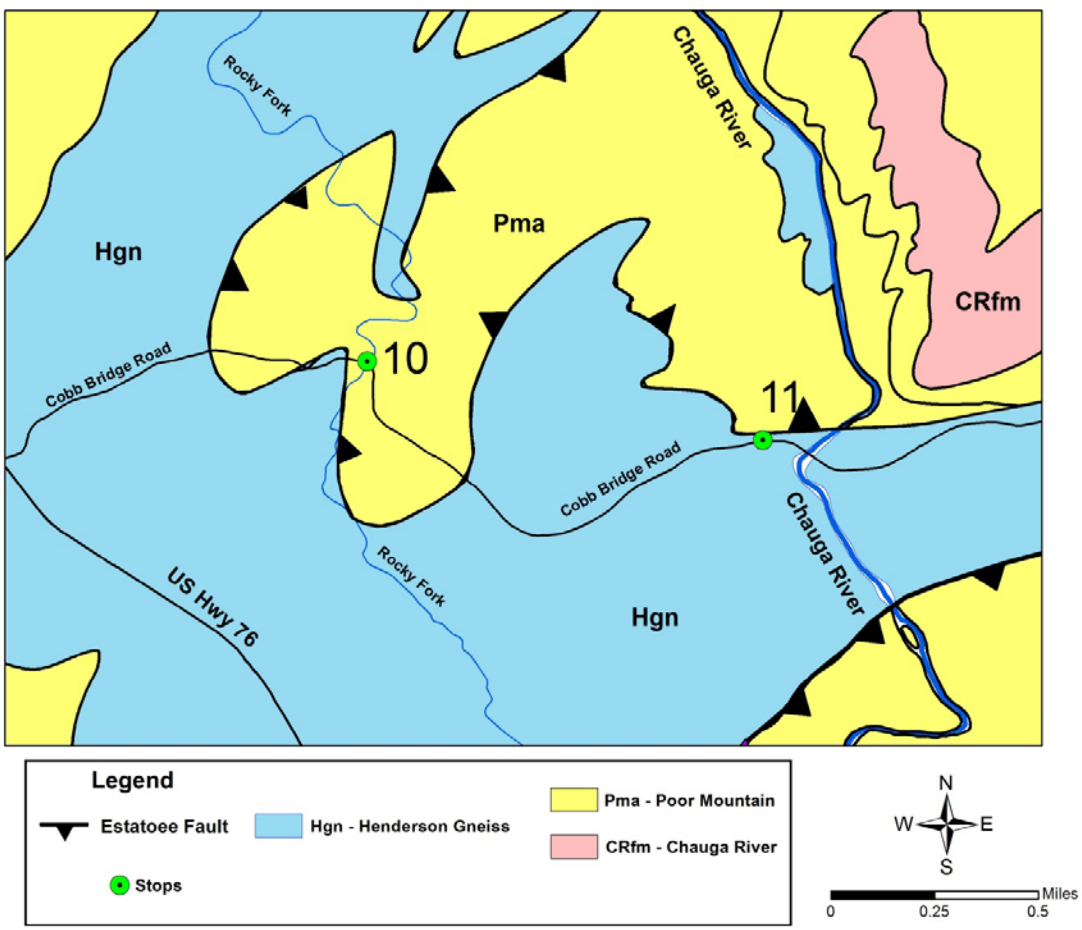

Figure 14. Structural relationships between Henderson Gneiss and Poor Mountain amphibolite along Cobb Bridge Road. Yellow unit here was mapped originally by Hatcher and Liu (2001) as the Transitional Member between the Chauga River and Poor Mountain Formations. A window through the Eastatoee thrust exposing Henderson is present between Cobbs Bridge Road and the Chauga River.

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